INFORMATION PROCESSING OF
DATA DESCRIBING ARBITRARY SOLIDS

SEMI-ANNUAL STATUS REPORT
December 1, 1965 to May 31, 1966

Herbert Freeman
Principal Investigator

June 1966

Sponsored by

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Prepared under
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LABORATORY
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DEPARTMENT OF ELECTRICAL ENGINEERING

SCHOOL OF ENGINEERING AND SCIENCE

NEW YORK UNIVERSITY bronx, new york 10453

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ABSTRACT

This status report summarizes the research work carried out during the period from December 1, 1965 to May 31, 1966 relating to the digital computer processing of data describing arbitrary solids. Specific investigations undertaken consisted of the hidden-line problem, the searching of a contour map for a specified terrain altitude profile, the development of a general three-dimensional data processing system for a PDP-5 computer (GRAPHPAK I), and a study of the recognition of three-dimensional objects from one or more of their perspective projections.

PERSONNEL

The following personnel contributed to the research described in this report:

Professor Herbert Freeman,	Principal Investigator
Mr. Philippe Loutrel,	Research Assistant
Mr. Stephen Morse,	Research Assistant
Mr. Michael Adamowicz,	Graduate Student
Mr. Andrew Rabinowitz,	Graduate Student

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INFORMATION PROCESSING OF DATA DESCRIBING ARBITRARY SOLIDS

I. INTRODUCTION

1.1 General

This status report describes the research studies carried out in the Department of Electrical Engineering, New York University, during the period from December 1, 1965 to May 31, 1966, relating to the information processing of data describing arbitrary solids. The work was sponsored by the National Aeronautics and Space Administration under grant NGR-33-016-038, and completes the first half of a planned two-year program.

1.2 Statement of Objective

The objective of the research is to develop techniques for the analysis and manipulation of arbitrary three-dimensional geometric configurations by means of a digital computer. One problem of particular interest is that of obtaining perspective projections of solids illuminated by an arbitrarily located point source of light. The techniques (computer algorithms) to be developed are to facilitate the solution of this problem as well as to be of general utility to the solution of a variety of other problems that involve the computer manipulation of data describing three-dimensional objects.

1.3 Investigations Undertaken

Four specific investigations were undertaken as part of this research effort during the past year. These are (1) the development of a programming system for obtaining perspective projections of three-dimensional objects (GRAPHPAK I), (2) a study of the topological and geometric properties of terrain contour maps and the utilization of these properties in the solution of the contour-map search problem, (3) the development of an efficient algorithm for the solution of the "hidden-line" problem, and (4) a study of means for reconstructing a three-dimensional object from one or more of its perspective projections. The results to date are briefly summarized in the following sections of this report. All four investigations are being continued into the second year.

II. GRAPHPAK I

GRAPHPAK I is a man-computer interaction program written for a PDP-5 computer* that permits the manipulation of data describing a three-dimensional figure "on line" under operator control. The figure may be any arbitrary three-dimensional "wire-frame" figure having up to 64 vertices. The coordinates of the vertices as well as all the lines connecting vertices must be entered in the computer by the operator. The operator may then instruct the computer to rotate the figure, to translate it, to change its scale, or to change the distance from the figure to the observer (thereby changing the perspective). The operator may also change the coordinates of any of the vertices or the lines connecting vertices. At any time he may request a plot on a CALCOMP plotter of the figure as currently stored in the computer memory. A true perspective projection of the figure will then be obtained relative to the specified position of the observer. To obtain an isometric projection, it is merely necessary to make the distance to the observer very large. The details of this program, together with illustrations of some of its capabilities are described in a report published during the past year.[1]

GRAPHPAK I is to be regarded as merely an initial step toward obtaining an effective computer program for the manipulation of data describing three-dimensional objects. Relatively modest objectives were set for this initial effort so that the computer program could be completed and made usable in a short time. In this way experience with such a

*Manufactured by Digital Equipment Corporation, Maynard, Massachusetts.

man-computer program could be obtained at an early stage of the work, and the results used to plan for an improved program at a later stage.

At the present time the most serious obstacles to increasing the capability of GRAPHPAK are the lack of an on-line oscilloscope with light pen and the limited memory of the PDP-5 computer (4096 words). Plans are being made to overcome both these limitations during the next year. In the meantime the program research work is being continued (on an "off-line" basis, however) on an IBM 360 computer. It is hoped eventually to tie the two computers together and then to have the PDP-5 serve as a remote, programmable console to the IBM 360.

III. THE CONTOUR-MAP SEARCH PROBLEM

As part of the research effort into the processing of data describing arbitrary solids, the solution of the so-called contour-map search problem was undertaken. In this problem an aircraft pilot is assumed to fly a path of known shape but unknown location or orientation over terrain for which a contour map is available. The pilot records the height of the terrain below the aircraft as a function of distance along his flight path, thereby obtaining a terrain altitude profile for the flight path. Upon return to base, the terrain altitude profile is entered in a computer together with the complete contour map data for the terrain over which the flight is believed to have occurred. It is then the task of the computer rapidly and efficiently to locate the flight path on the contour map.

A variation of this problem is contour-map navigation, in which an aircraft is navigated on the basis of terrain altitude information using an on-board computer with stored contour-map data.

Applications of contour-map searching (or navigating) for aircraft can be expected to be limited to special situations because of the many alternate position-locating and navigating means available on the surface of the Earth. An advantage of the contour-map technique is that it is independent of weather conditions and electromagnetic disturbances. No limitations are imposed on length of flying time or amount of maneuvering permitted. It is merely necessary that contour maps of the terrain exist. Moreover in areas where other navigating means are not so readily available, such as on the surface of the moon or below the surface of the sea, contour map searching may be the only means for locating one's position with any degree of precision.

The difficulty associated with the contour-map searching problem does not lie in the concept of the problem itself but rather in the necessity of finding an <u>efficient</u> way to accomplish the searching. The problem belongs to the class of the so-called large-scale problems which are identifiable by their characteristic of having enormous data processing requirements. This usually means that they lie beyond the capabilities of even the largest computers as soon as realistic-size situations are considered. The solution of these problems thus is not the finding of some algorithm that is theoretically capable of yielding the desired results - a brute-force method is almost always readily at hand - but rather in finding a heuristic scheme that makes it <u>feasible</u> to solve the problem in a reasonable time on a computer.

In the approach taken here, use was made of certain contour-map encoding and analysis techniques developed earlier.[2-4] It was found that the solution of the contour-map searching problem could be greatly simplified by first constructing a graph which displays the topology of the contour map. Such a graph enables one quickly to eliminate large sections of the map as areas where the flight path associated with a particular terrain altitude profile could not possibly be located. By thus leaving only a few "eligible" areas, the scope of the problem is severely reduced.[5] For example, if the terrain altitude profile shows two altitude peaks of 10,000 meters separated by a valley of an altitude of 4000 meters, clearly only those areas of the contour map need be searched where such an altitute pattern exists.

After the contour map search has been narrowed to the "eligible" areas on the basis of the map's purely topological properties a second search phase is entered in which the map's geometric properties are considered. From these geometric properties, maze-like regions are constructed in which the flight path may lie. The most likely maze is then searched first to see if a precise fit of the terrain altitude profile is possible; if not, the next-likely maze is examined, etc., until the best fit of the profile is achieved. At this point the flight path will have been located on the contour map.

During the past year a report was written describing the initial part of the search procedure, that is, the part using the map's topological properties. Subsequently the geometric-property procedure was worked out and tested by means of search problems on both simulated contour maps and on a contour map of the Fall River Pass quadrangle in Colorado.* All computations were performed on a CDC 6600 computer. The work has become the subject of a doctoral dissertation and is now nearly completed. The full results are expected to be published toward the end of the summer of 1966.

*Obtained from the U.S. Geological Survey, Washington, D.C.

IV. THE HIDDEN-LINE PROBLEM

Of particular interest in the research described here is the problem of finding the surface portions of an arbitrary three-dimensional object that are visible to an observer at a point p_1 when the object is illuminated from a source of light located at some point p_2, where the points p_1 and p_2 may be anywhere exterior to the object. In the initial approach to solving this problem it was decided to restrict the objects to polyhedra. By considering only polyhedra, the problem reduces essentially to the so-called hidden-line problem. This latter problem is the one of determining the edges (or parts of edges) of a polyhedron that are visible from an observation point not on the surface. If the polyhedron is illuminated from a point other than the observation point, one must determine those edges (or parts of edges) visible to <u>both</u> the observation point <u>and</u> the illumination point.

During the past year an intensive study was made to develop an algorithm for solving the hidden-line problem for the general polyhedron.* Just as with the contour-map search problem, the main difficulty lies in finding an <u>efficient</u> procedure that imposes minimal requirements of time and memory space on the computer. However, in the contour-map search problem the desired procedure is of the heuristic type; for the hidden-line problem an algorithm is required.

The first step in the work was to find a suitable scheme for describing the polyhedra. It appeared best to describe the polyhedra by giving the X,Y,Z- coordinates of the vertices, numbering the vertices

*The only polyhedron excluded was the one-sided polyhedron, which like the Klein bottle, has no distinct "inside" or "outside".

(in any order), and then specifying the faces in terms of sequences of vertex numbers. The sequences were formed by simply listing the vertices for each face in a clockwise sense when seen from the exterior of the polyhedron. This scheme makes it very easy to determine the outward normal of each face.

An edge of a polyhedron may be invisible for two distinct reasons: (1) because it is the intersection of two faces that are directed away from the observer, or (2) because the edge, although facing the observer, is masked in part or in toto by another part of the polyhedron. Clearly, only the first reason can apply if a polyhedron is convex.

The principle employed in the algorithm is to determine first all edges that are invisible for reason (1), and then to find those invisible partially or totally for reason (2). Any remaining edges will then be entirely visible.

At the present time, all major parts of the algorithm have been outlined. Approximately half of the algorithm has already been programmed in FORTRAN and debugged on an IBM 360/30 computer. A plotting routine has been written and debugged on the PDP-5 computer which will plot the actual perspective projection of the polyhedron, with "visible" edges shown solid and "invisible" edges shown dashed for any specified exterior observation point. This routine is an extension of GRAPHPAK I (described in Section II). A modification planned for the near future will enable the routine to accept the data output from the IBM computer via an on-line card reader. A technical report describing the work to date on the hidden-line problem is expected to be completed by early fall 1966.

V. RECOGNITION OF 3D OBJECTS FROM THEIR PROJECTIONS

During the past year a study was started to determine to what degree it is possible to recognize a three-dimensional object from one or more perspective projections of the object. This problem arises for example in connection with space exploration where a set of photographs of an unidentified object are obtained and it is desired to develop as complete as possible a three-dimensional description of the object. The solution of this problem requires the correlating and combining of different views of the object, and the interpolation and extrapolation of the information thus obtained to those parts of the surface for which no views are available. The extrapolation must be achieved using concepts of symmetry, similarity, balance and any others that may be applicable. Of course the greater the regularity of the object, the simpler this task.

In addition to the identifying of unknown objects in space, applications of this problem also exist in the area of deep-sea explorations, in microphotography, and in the photography of transient phenomena (such as, for example, the reconstruction of the various stages of disintegration of an exploding object).

Work on this investigation was started toward the latter half of the past year. The initial effort was concentrated on the recognition of simple, regular polyhedral objects, using only one or two photographs of the objects in each case. Simple polyhedral objects were constructed and photographed from various observation points and under various lighting conditions. A study was made of certain precedence relations that can be established regarding the portions of an object as they will be apparent in a photograph taken from a particular observation point.

This work is still in its early stages and the exact course the research will take has not been firmly established as yet. The work thus far is described in a report currently in preparation.[6]

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